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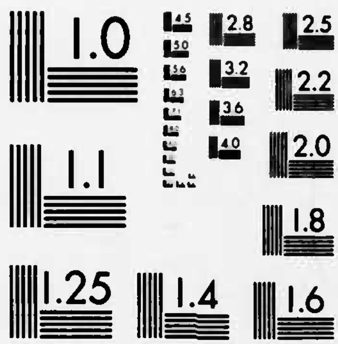
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NAVAL TRAINING SYSTEMS CENTER
ORLANDO, FLORIDA

Technical Report: NTSC TR88-024

SIMULATION AND TRAINING NETWORK TECHNOLOGY

CENTER OF EXCELLENCE FOR SIMULATION AND TRAINING TECHNOLOGY

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This report summarizes the findings of a study of simulator networking feasibility under contract to NAVTRASYSCEN. The study defines networking requirements in terms of hardware, software, synchronization and data exchanges using F-14 and E-2c Weapons Systems Trainers as a point of reference.

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30 April 1988

DR. WEI CHEN
University of Central Florida
P. O. Box 25000
Orlando, FL 32816

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EXECUTIVE SUMMARY

The advantages of integrated training, in which separate elements of a battle force train together in a simulated warfare scenario, are well recognized. The Commander, Training Command, U.S. Pacific Fleet (COMTRAPAC), with the support of Chief of Naval Education and Training, has recommended linking existing training systems in the San Diego area. The Naval Training Systems Center awarded a contract to Dr. Wei Chen of the University of Central Florida to examine the feasibility of such a network with particular emphasis on networking E-2C and F-14 Weapons Systems Trainers. His task was to define the requirements in terms of simulator synchronization, data exchanges, and necessary hardware and software and to explore the applicability of emerging network technologies to the realization of the objective.

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SECTION I

INTRODUCTION

The objectives of this study were to explore the issues involved in linking existing complex training systems such as E-2C and F-14 Weapons Systems Trainers and to recommend a networking architecture to accomplish this goal.

This report delineates the requirements of the training system network as a point of origination for a proposed network based on long haul data transmission operations. SIMNET, an advanced research project of the Defense Research Projects Agency (DARPA), demonstrated the ability to network large numbers of simulated, low-speed combat vehicles using local area networks and long haul transmission media. It served as a focal point of this study.

The study indicates that networking of training systems of the complexity of the E-2C and F-14 Weapons Systems Trainers is feasible. A method for creating such a network is proposed in this report.

SECTION II

THE SIMULATOR NETWORKING REQUIREMENTS

2.0 The simulator network consists of a collection of individual simulator devices capable of communicating and interacting with each other in real time. The networking problem is identified as the design and implementation of the means of control and communication among the simulators, such that specific training objectives can be accomplished. The problem can be defined in terms of networking requirements areas for supporting real time simulator network operations, namely, data transfer, controls, and communications. These requirements will be examined in the following sections.

2.1 DATA TRANSFER

Interactive operation requires that the participating simulators transmit and receive simulator states and status to and from each other. This data transfer process involves computer data representing vehicle location, attitude, velocity, operating modes, radio settings, and other on-board systems operating conditions.

In order to assure the proper dynamic characteristics necessary to support the interactive training tasks, the data transfer process must satisfy a well defined and constrained set of data transfer requirements in terms of update or sampling rates, transport delays, and any time lags incurred during the process of data transfer. In this section, the volume of network traffic resulting from data required at the chosen update rate is considered. This data is characterized as: parameters list, time critical data, real-time log, and off-line data. Discussions of transport delays and network delays will be presented in Section III.

2.1.1 Parameters list: The parameters list defines the volume of data that must be presented on the data bus at different update rates. Therefore,the two major concerns here are (i) the sizes of the data sets to be exchanged on the network, and (ii) the frequencies at which the data sets have to be updated. The product of the data set size by the corresponding update frequency represents the data rate requirement due to that particular data set. The sum total of the data transfer rates of all the data sets represents the overall data load of the network. For the purpose of this analysis, we can divide the parameter list into the following two categories:

2.1.2 Time Critical Data: This category includes the dynamic states and real-time status information that are presented in synchronism with some predetermined time frame sequences. Such data are said to be time critical because they represent dynamic states in which the time frame sequences define and support the temporal correctness of the simulation process. Typical examples of time critical states include vehicle positions, attitudes and their derivatives. Computationally, such states are usually the outcomes of numerical integration algorithms.

2.1.3 Real-time Log: This category includes sampled data points of the simulator run time (real time) states and status. This includes some of the time critical data described previously. The focus of this category is the performance of the instructor operator function where real-time simulator data are logged for post exercise critique and debriefing. This data category is established to motivate design consideration of the networking requirements for the NIOS (network instructor operator station) operation.

2.1.4 Off-line Data: The off-line data include those that are required for setting up the training exercise and for supporting administrative tasks. The off-line data are exchanged among the simulators and the network instructional staff for establishing simulators initial conditions and for specifying the membership of participants for given training exercises.

2.2 CONTROLS

The performance of the training mission requires a single point control of the network system. The control functions include the following.

2.2.1 Run Control: Control signals and status feedback are required to synchronize the operation of individual simulators and to place the network in the selected operating mode and network configuration. The run control operation as well as the other control functions will require communication among the instructor operator stations (IOS) of the individual simulator systems and the network instructor operator station (NIOS).

2.2.2 Exercise Control: The NIOS supports the training exercise through the various controls and monitoring features. Such features provide for functions such as display pages and manuals for initial condition selection, individual simulators performance monitoring, data logging for debriefing, preprogrammed course of exercise, and other demonstrations and instructional operations. The exercise control must also support the communications between the various instructional staff members to coordinate the execution of the training exercise.

2.2.3 Voice: Voice communication must be provided between and among the instructors and the trainees. The voice communication paths are required to provide for the crew team intercoms, the radio communications simulation with instructors role playing as the participants in the radio traffic, as well as the necessary voice communication among the instructional staff.

2.2.4 Exercise Planning: Due to the complexity of network based exercises and the dispersed locations of the physical devices, exercise planning stands out as a resource intensive and recurring task. The exercise planning includes the following requirements:

2.2.4.1 Exercise design (Authoring) - The NIOS software establishes conditions to define and construct exercise sequences and procedures.

2.2.4.2 Network generation: Based on the planned exercise sequence, a network configuration must be generated to specify the membership of participating simulators, network interconnection, and the communications software installation. A corresponding set of user instructions should also be generated for the instructional staff.

2.2.4.3 Network prerun: Upon the completion of the network generation sequences, a network status check should be performed to check the validity of the networked system. The network prerun software should activate the self test and diagnostics programs of the individual simulators to be networked as part of the network system validity check. Due to the complexity of the simulator systems, default conditions or other means to cope with nonavailability of individual simulator systems or subsystems must be included in the planning process.

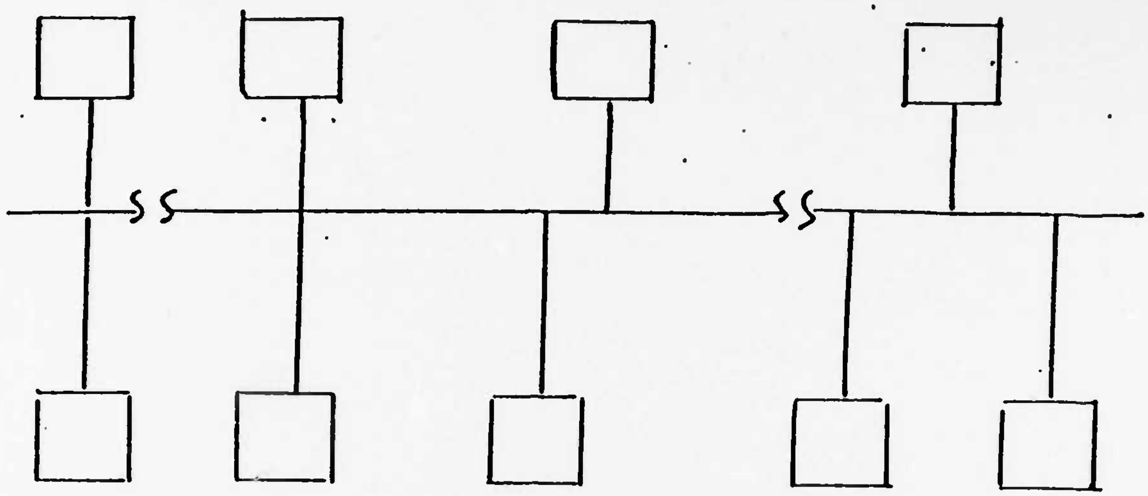
2.3 COMMUNICATIONS

The availability of technically adequate means of communications at affordable cost levels has always been an up-front concern in ascertaining simulator network feasibilities. In this section, the outcome of a survey in seeking available means of implementing a simulator network is presented together with other key considerations in network implementations such as transmission errors and data security.

The communications among the individual simulators in a network involve three key areas of consideration. These three areas, namely network architecture, protocol, and communications medium, describe the capabilities as well as the constraints of the networks.

2.3.1 Network Architecture: The Network architecture depicts the topology of the network in terms of data nodes, their interconnections, and the data transfer paths. Comprehensive descriptions of network topologies are provided in most text books on the subject of computer networking and data communication [See for example Ref. 1]. Of the commonly used data network topologies, the ring/loop and tree type structures are best suited to asynchronous applications where data throughputs demand is modest and delays introduced by intervening nodes are not significant. For the problem of simulator networking, it is envisioned that most communications would be between one central node and each of the remotely-located outlying nodes. For these reasons, a star configuration should be most appropriate for this application. At the controlling node, a multidrop bus configuration will be recommended for interconnecting the component network interfaces. Thus we will concern ourselves only with the star and multidrop bus configurations as shown in Figure 1.

The star network structure has a central node which acts as the data exchange clearing house. This centralized node provides for the control and synchronization of all the communications controllers interfacing to the



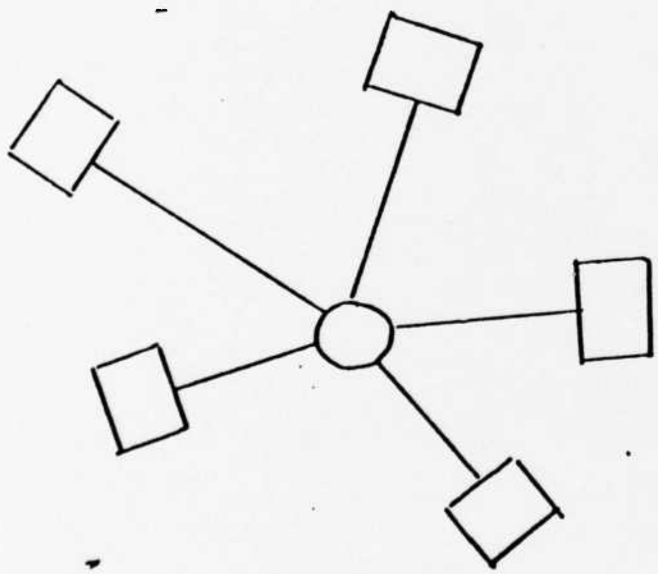


FIGURE 1. MULTIDROP & STAR BUS CONFIGURATIONS

serial data links. The simulator network operation requires that a dominant central node exist to provide the overall control functions. The instructor/operator station functions also require that much of the state information be handled at this central node to support initialization and the evolution of training scenario. Thus the preferred network architecture is a star topology.

The multidrop configuration, unlike the star, provides a direct path of communication among the nodes via a common bus. A dominant node controls access to the bus.

2.3.2 Network Protocol: In order to accomplish the data exchange between computers, it is necessary that all the steps taken by the two parties (computers) are predetermined. Protocol is a delineation of rules governing the exchange of data between the sending and receiving parties. Such rules define both the step-by-step procedures and the various states of the computers and their interface through the entire course of interaction. The recognized standard for protocol is that proposed by the International Standard Organization (ISO), and it is common practice to specify communication protocols in levels akin to the seven levels (or layers) adopted by the ISO. An example of the protocol levels as proposed by Tanenbaum [Ref. 1] is shown in Figure 2.

Independent of the specific communication protocols selected and adhered to, the use of a common standard protocol represents the single most important implementation aspect. This will be kept in mind during the process of synthesizing the proposed network solutions. Furthermore, the reuse of software modules at the various levels of protocol handling is also a key design consideration.

2.3.3 Communications Medium: The selection of the communications medium is obviously highly dependent upon the physical distances between the simulators. This section will examine both the long haul and the local area network design considerations.

2.3.3.1 Long Haul Communications. An in-depth survey of the available long-haul communications medium was covered in a technical report prepared by the Training Analysis and Evaluation Group (TAEG) [Ref. 2]. The survey covered the various commercially available communication networks in terms of their performance and costs. The following discussions of high bandwidth lines and voice grade lines are based on this study.

2.3.3.1.1 High Bandwidth Lines: High bandwidth phone lines are considered to be those with data rates above 19.2 Kbps. At the high end are the T1 and T3 dedicated lines with bandwidths of 1.544 Mbps and 450 Mbps, respectively. The data rates required for the networking of training systems do not demand the dedicated use of T1 or T3 or the costs, which are around $25,000/month for T1 and more for the T3. It should be noted, however, that T1 lines can be "channelized," dividing the bandwidth among 24 separate applications. A "Wideband digital transmission" which encompasses bandwidths between 19.2 Kbps and 1.54 Mbps is the bandwidth of primary interest for this application. Thus we concentrated our survey efforts in gathering vendor data in this area.

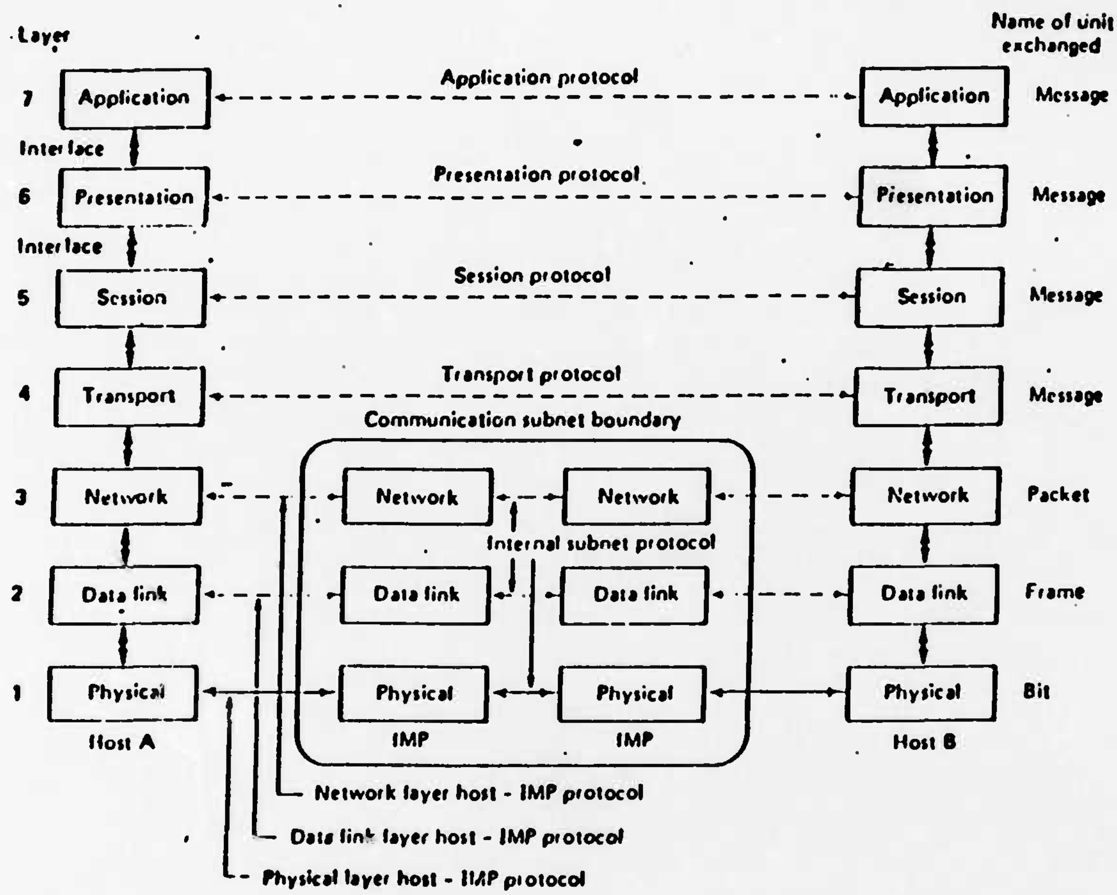


FIGURE 2. NETWORK PROTOCOL LAYERS

Wideband digital transmission is offered by AT&T's Dataphone Digital Service (DDS), which offers speeds of 19.2K bps and 56K bps. Instead of modems, DDS service requires a Channel Service Unit (CSU), to terminate each line and a Data Service Unit (DSU), which provides the digital interface to the user's equipment. The CSU and DSU are normally marketed together as a DSU/CSU combo. Service-Level objectives include a 99% availability rate. Actual error rates for DDS average 1 in 10^9 to 10^12 bits.

Some DDS users require error rates even better than this, and several schemes have been developed to achieve them. The most popular method to correct errors with DDS is the use of a secondary diagnostic channel. This channel uses a lower bandwidth to detect/correct transmission errors. AT&T defined DDS with a secondary channel (technical Publication 62120), but has not yet filed a tariff for this service. According to Analysts, AT&T is waiting until a pair of the Bell Operating Companies (BOCs) is prepared to offer the service. Several BOCs have filed, or are planning to file for the tariff. Network application under development now for use in the next couple of years should probably be designed under the assumption that the secondary channel will be available.

In the meantime, some vendors are providing for secondary diagnostic channels using the current DDS offerings. Infinet, for example, offers a DSU/CSU unit that simulates the secondary channel by multiplexing diagnostic information into any available time on the link. Since the diagnostic information defers to ordinary data, a heavily loaded line will not be fully protected using this scheme.

Several vendors have already built secondary channel capability into their DSU/CSU pairs in anticipation of AT&T's support of a separate diagnostic channel. In addition several vendors offer a DSU/CSU with a separate asynchronous channel for diagnostic purposes. Paradyne offers a DSU/CSU that uses both approaches. It has the capability to handle the DDS secondary channel, and also simulates a secondary channel. In addition, the Paradyne 3058 also includes a built in Bell 103 modem that automatically calls for help if the DDS link goes down.

DDS users can also use their own schemes to protect their transmissions, in addition to mechanisms provided by DDS. These schemes normally involve the use of Cyclic Redundancy Codes inserted at the end of each transmitted frame.

It is interesting to note that many real-time networks do not employ any error correction schemes at all. SIMNET, for example, allows for the detection of errors, but has no scheme to correct the errors. Voice and video networks often do not even detect errors. For the real-time network proposed, a frame that is completely destroyed is simply lost, since it is assumed that almost all of the bandwidth will be devoted to data transfer. The detection of errors obviously requires the use of additional bits. For most situations, the impact of a missed update should be minimal. The above discussion assumed the use of dedicated leased lines. DDS also offers a service analogous to the dialed long distance telephone network. AT&T's Switched 56 service provides 700 numbers for 56K transmission in some 60 odd cities, including areas such as Orlando, San Diego, and the Washington D.C. area.

- Costs of DDS Service -

A breakdown of monthly charges for service between Orlando and San Diego offers a good example of expenses to be incurred using DDS:

Nonrecurring charges.......$1575
Recurring charges.......... 5780
DSU/CSU per node........... 1100
DDS Secondary Channel...... ?

AT&T's Switched 56 to the same destination costs:
Nonrecurring charges.......$2000
Charge/minute.............. ?
DSU/CSU per node........... 3500
Secondary channel.......... ?

Nonrecurring charges in both examples include the physical local loop to the regional Bell Operating Company. The DSU/CSU for the switched service is much more expensive, and is less available than regular DSU/CSU combos for switched DDS service. General DataComm and Kentrox Industries offer DSU/CSU combos for switched DDS service. Some additional cost data on 56Kbps DDS DSU/CSU combos are as follows:

. Infinet, (North Andover, Mass.) offers the Infinet Integrated Diagnostic Modem IDM 556 for $1995 which uses time division multiplexing to simulate a diagnostic channel.

. Amdahl's Communications Systems Division (Richardson, Texas) offers the DSU-II 56 for $1350, which includes an async secondary channel with speeds of 300, 1200, 1800, or 2400 bps.

. Paradyne's 3056 BSU, which sells for $1100 simulates a diagnostic channel (compatible with Paradyne's Network Management System), supports DDS's planned secondary channel, and has a built in asynch modem which calls for help if the DDS line goes down.

. General DataComm (Middlebury, Conn.) offers a DSU/CSU for $3500 for use with AT&T's Switched 56 DDS service.

. Kentrox Industries (Portland, OR) offers a similar Switched 56 unit for $3500.

2.3.3.1.2 Voice Grade Communication: This category of phone line includes data rates of 300, 1200, 2400, 4800, 9600, and 19,200 bps. The higher voice grade speeds are possible using advanced data compression and error correction schemes, and leased (D1- conditioned) voice-grade lines. The protocol used for error correction/data compression determines the compatibility of any two modems. Popular protocols include Microcom's three Networking Protocol (MNP) standards, Hayes' X.25 based standard, and CCITT's Modem Working Party Standard.

Vendors of high speed voice-grade modems include:

Digital Communications Associates, Alpharetta, GA
Microcom, Norwood, MA
Racal-Vadic, Milpitas, CA
Fastcom Data Corp, Reston, VA
Case Communications of Columbia, MD.
Hayes Microcomputer Products, Atlanta, Ga.
Paradyne
Anderson Jacobson, San Jose, Calif.
Infinet, North Andover, Mass.
Codex, Mansfield, Mass.
Racal-Milgo, Ft. Lauderdale, Fla.
NCR Comten, St. Paul, Minn.
Fijitsu America, San Jose, Calif.
General Datacomm, Middlebury, Conn.

2.3.3.1.3 Integrated Voice/Data: AT&T has designed and is currently installing for DOD a customized, all-digital integrated network, the Defense Commercial Telecommunications Network (DCTN) that will carry dedicated and switched voice, dedicated data, and video traffic among hundreds of different locations across the country. Services on DCTN can be expanded as the situation demands as in the case of networking trainers at distant sites. It is probably the most economical means of implementing training systems networks.

2.3.3.2 Local Area Networks: In cases where individual simulators are located within the coverage of a local area network (LAN), the use of the LAN is probably the best choice for the communications network. LAN capabilities are offered by most major computer vendors such as IBM, DEC, Wang and many specialized firms in communications networks. The LAN represents a low cost and high performance communications network if the geographic coverage is limited to within a few miles.

2.3.4 Transmission Errors: The transmission of data over long distance incurs finite transmission error rates. Various means and techniques are available to detect and correct transmission errors. However, in view of the relatively infrequent error occurrence (1 in 10 billion bits), the first order design question here is to consider the effects of transmission errors. For example, for a 56K line, at this error rate, a bit error will occur approximately every 50 hours of operation.

If the error occurs in position, velocity or any other simulator states, this may cause disruption of training exercise for one or more participants, but will not cause the whole network to "crash." If this type of error starts to become bothersome, a rate of change limit may be implemented by the communications processor such that updates may be computed from the previous frame's data.

The network control and status signals may have to be guarded against errors to avoid unintended changes which may cause disruptions that are systemic in nature. At this point, again in view of the low error rate, we will consider the possibilities of error effects, but will not include any measures to cope with transmission error unless operations in the future should indicate otherwise.

2.3.5 Data Security: Transmitting data through phone lines or any other exposed medium implies security risk. The most commonly used protection for data security within the context of data networks is the process of encyption. We will not carry out any discussion here on the encoding and decoding schemes or any other physical security measures and procedures. For the purpose of this study, we are aware of the data security risks, and on the other hand all the data security measures are available. Specifically, in cases where encryption is appropriate, the communications processors can be used for such encode/decode tasks.

2.3.6 Tradeoffs: During the current study in simulator networking, we make the following observations:

- The communication medium represents the bottleneck in terms of both data transmission throughput and costs.

- Means of trading between communications resources and computing resources exist for achieving the goals of simulator networks.

- The rate of improvement in cost/performance for computational resources far outpaces those for communications resources.

SECTION III

THE SIMULATOR NETWORK

In this section, a simulator network is proposed for feasibility evaluation. During the process of this design study, the following two guidelines were adhered to:

(1) A general solution is sought for the simulator networking problem. The particular solutions for networking existing simulators such as the E-2C trainers and F-14 WST are included as a specific case. As such, the proposed network design addresses the communication and control requirements pertaining to the longhaul network, where the requirements are much more stringent. The same system design can readily be applied to simulator networks served by local area network implementation. A natural extension to the above could include applications where a mix of longhaul and local area networking arrangements is used to support the given simulator network requirements.

(2) The design study addresses only parameters that are directly relevant to characterizing and affecting the tactical situations and environments. In other words, only the tactical and instructional data which are to be communicated through the network are treated in this study. The local systems aspects of the individual simulators, such as flight dynamics, systems management, and operator skills monitoring and evaluation are not included as part of this study. However, we do recognize the fact that the above mentioned local systems parameters are important and fundamental to the operation of the individual simulators in the network.

3.1 Simulator Descriptions: In the three subsequent subsections, we characterize the individual simulators in terms of their capabilities, functions and communications/controls requirements. The simulator characteristics are merged with the networking requirements to formulate a networking approach in the form of a proposed network solution. The proposed network is then analyzed in terms of implementation requirements to determine the feasibility of networking large simulators. To provide additional perspective, an F/A-18 Operational Flight Trainer was studied to determine any major network loading requirements not revealed by the F-14A WST investigation.

3.1.1 The E-2C Tactics Trainer [Ref. 3]: The E-2C Tactics Trainer, Device 15F8B consists of a simulation of the Control Indicator and Computer (CIC) compartment of the E-2C aircraft and all the necessary computer, video generation, instructor consoles, audio systems, etc., required to conduct realistic training sessions at a ground base for the three CIC crew members. Where possible actual aircraft hardware is used in the trainer. The floor plan for the E-2C Tactics Trainer for the Naval Air Station, Norfolk, Virginia, is shown in Figure 3.

The trainer consists of three major functional areas. Trainer personnel stations are located at two of these areas, the Problem Control Complex and the Trainee Complex. The third area consists of the simulation equipment, mainly the simulation computer (SIMCOM) and the Radar/IFF Simulator (RIS). The following paragraphs briefly describe the two interactive work areas.

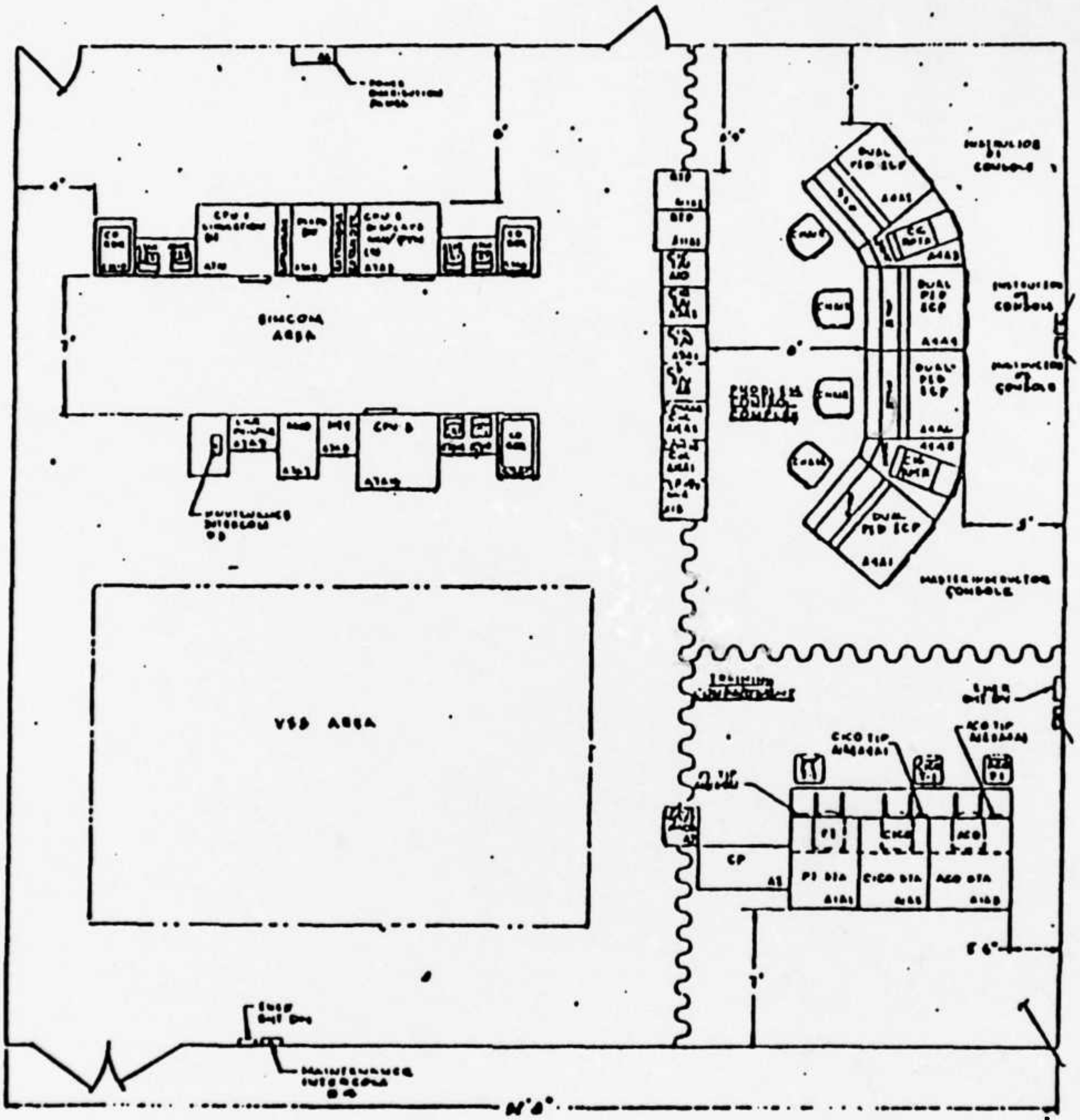


FIGURE 3. E-2C TRAINING SYSTEM FLOOR PLAN

3.1.1.1 Problem Control Complex. The Problem Control Complex (PCC) provides three instructors and a master instructor with facilities to initiate, monitor, control and modify the simulated training problem, communicates and evaluates trainee performance. The PCC, including the Master Instructor Station, consists of eight Primary Interactive Displays (PID), four sets of Special Function Keyboards (SFK), two Modified Standard Keyboards (MSK), two Control Indicator Group (CIG), Repeater Indicator Units and Associated Power Supplies, a Trainee Monitor Panel (TMP) and four Instructor Communications Panels (ICP).

3.1.1.2 Trainee Complex. The Trainee Complex consists of an area of the trainer that contains the Trainee Stations (an E-2C CIC compartment), three Trainee Instructor Stations, a Forward Equipment Simulation Console and a Computer Programmer, OL-77/ASQ. The trainer area provides ample room for individualized training and is equipped with a controlled lighting system to permit selective room darkening.

3.1.1.3 E-2C Aircraft Description: In order to gain understanding of the training capabilities of the E-2C Tactics Trainer, the E-2C Aircraft Description is presented here to illustrate the functions of the Control Indicator and Computer (CIC) equipment within the role and mission capabilities of the E-2C aircraft.

The Grumman E-2C Hawkeye is an all-weather, carrier-based AEW/CIC (Airborne Early Warning/Control Indicator and Computer) aircraft that patrols task force defense perimeters to provide early warning of approaching enemy aircraft and to vector interceptors into attack positions.

In addition to this primary AEW function, the Hawkeye can also provide strike and traffic control, area surveillance, search and rescue guidance, navigational assistance, and communications relay.

The E-2C is deployed to provide Airborne Early Warning (AEW) for a naval task force, and operates from an assigned station. In this mission, the Airborne Tactical Data System (ATDS) units, of which the E-2C is a part, are deployed to continuously search the surrounding area for targets. The E-2C Radar makes a 360 degree scan of the area every 10 seconds. Through the use of its APS-125 radar, IFF and PDS sensors, the E-2C can monitor a large area for both airborne and surface targets. Radar returns from targets are processed to identify and track targets.

Automatic screening and segregation of friendly and unknown targets are accomplished by high speed, real time data processing aboard the E-2C. The data developed in the E-2C is provided to the E-2C operator on all tracks within the range of the E-2C detection system. The following functions (see Figure 4 for interrelationships) are performed by the E-2C in its AEW role:

* Automatically detects and tracks airborne and surface targets within the surveillance volume.

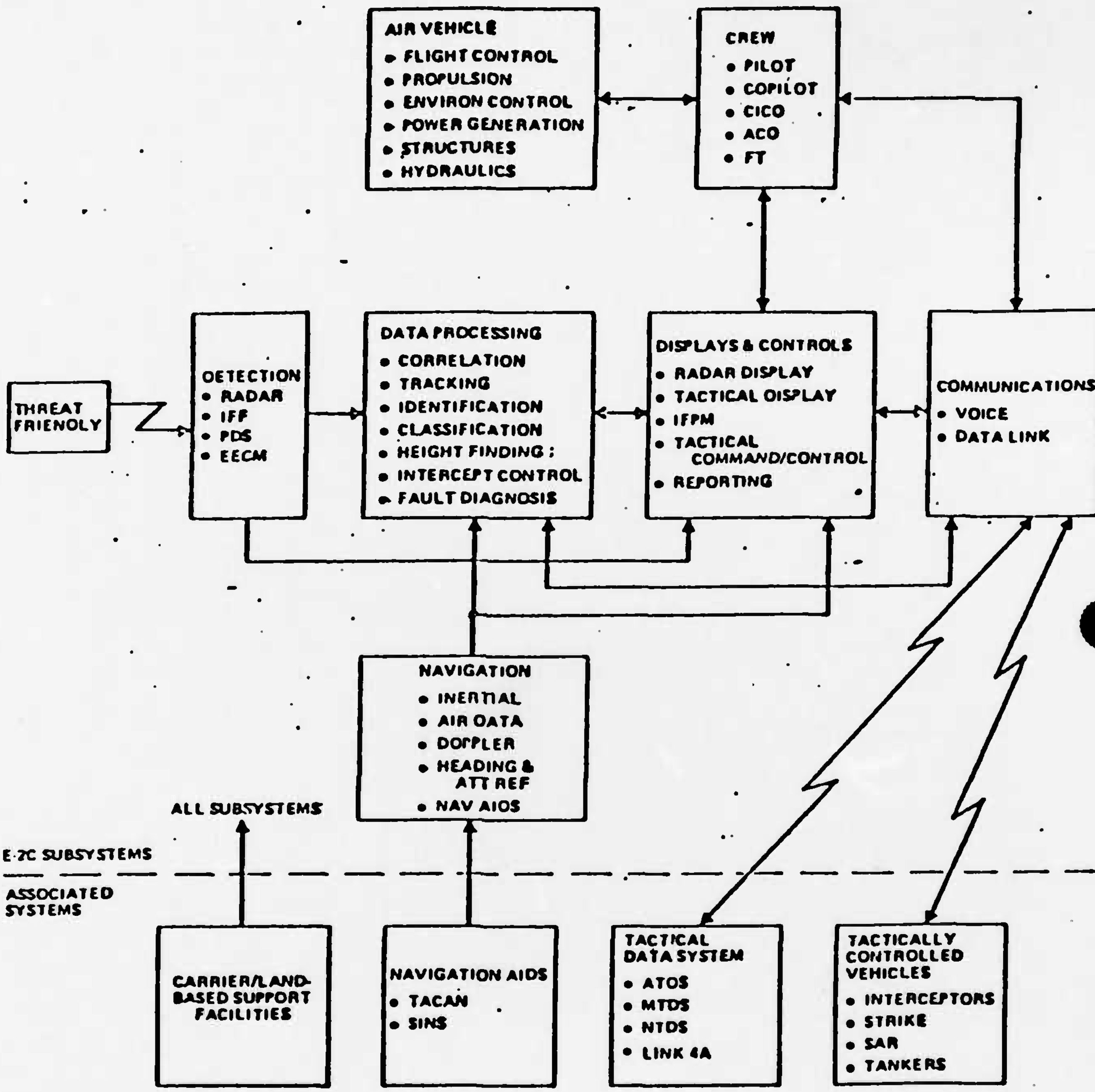


FIGURE 4. E-2C FUNCTION

* Automatically identifies properly equipped friendly targets.

* Automatically determines altitude of overwater targets.

* Automatically correlates new data with the target tracks in storage. Rate aided tracks or overland targets may be established manually.

* Automatically initiates tracks on new targets.

* Displays tracks for evaluation and categorization.

* Automatically reports tracks to the TDS.

* Automatically accepts and displays tracks reported by the TDS.

* Accepts manually inserted data.

* Determines position of ownship for target reporting and data stabilization.

* Generates guidance commands for control of other aircraft.

* Automatically transmits guidance commands to data link equipped aircraft.

* Automatically monitors internal functions and alerts the operators when a malfunction occurs. The major increase in capability in E-2C is the new Advanced Radar Processing System (ARPS), the APS-125. This system allows automatic detection and tracking overland as well as overwater and represents a significant step forward in mission effectiveness.

The Intended Use: The E-2C. Tactical Trainer provides the means of obtaining the knowledge and skill in the operation of the CIC and of the system (RADAR, IFF, ECM, Communications, Link 11, Link 4A, Passive Detection System, etc.).

The trainer also provides for acquiring knowledge and skill for the operation of the in-flight performance monitor (IFPM) system. Such knowledge and skill are also required in detecting and correcting the various system malfunctions. Another important training objective is to provide for skills acquisition to assure effective IFPM system operation by circumventing various system malfunctions.

Operationally, the trainer supports missions in crew coordination and in situational awareness training based on the knowledge of the tactical environments as presented by the various display and communications systems.

Data Communications Requirement: The data communication required between the E-2C trainer and the network instructor operator station (NIOS) consists of the various sensor data, vehicle positions, and control information for simulator network operations. A preliminary estimate indicated that the transmission of such a collection of information through longhaul medium may

be very costly and burdensome. An obvious solution here is to collocate the E-2C Tactical Trainer with the NIOS. This allows the use of local area network between the E-2C Trainer and NIOS, and the data transmission can be accomplished with little concern for resource limitations.

The collocation of the E-2C trainer and NIOS also avoids much of the duplication in the elaborate E-2C instructional system. As such the instructional personnel for the E-2C trainer may also be tasked to support network training operations with a few additional operator/instructors.

3.1.2 The F-14 Trainer [Ref. 4]. The F-14A Aircraft Weapons System Trainer (WST), Device 2F112, provides full scope simulation for Pilot and Naval Flight Officer (NFO) Stations of the dual seat, dual engine F-14A aircraft. The trainer consists of a two position cockpit, an instructor/operator station (IOS) complex, and the general purpose computer complex which provides for the control and operation of the WST. The device is designed with a wide angle visual system which is used to support air combat maneuvering simulations.

3.1.2.1 The Intended Use: The principal uses for Device 2F112 are for aircrew (pilot and NFO) flight proficiency training, tactics training, integrated crew training, and for maintenance of contact and instrument flight in the F-14A aircraft. The WST also supports training tasks in normal and emergency instrument flight, radar ground mapping, airborne target acquisition, electronic warfare, starting, shutdown procedures, and delivery of all ordnance capabilities of the F-14A aircraft.

We note that the use of the WST as a network "node" involves only a subset of the overall device capabilities and features. Careful selection of features and their related parameters for representation is an important step to keep data communication requirements to a minimum.

3.1.2.2 Data Communications Requirement: The data communications to support networking operation of the F-14A WST include the following four categories of information.

(1) Ownship data: The ownship data includes the position, attitude and rates of changes of the F-14A aircraft. Other information may include the externally visible aerodynamic configuration changes such as external stores, wheels, flaps, slats, etc.

(2) Situational data: These are mainly data to be extracted from the network in terms of the targets, threats, and EW signals. Data Link, radio frequency selections, counter measures and other environmental data are also included. This represents the data required to construct the tactical environment for the training mission.

(3) Control data: This includes the various control and synchronization signals to be received from the network instructor operator station (NIOS). In return, F-14A WST status, and commands acknowledgment are to be sent to the NIOS via the network media.

(4) Voice: Selected audio interchange may be required for radio communication simulation. A delineation of communications requirement is shown in Table 1.

TABLE 1. F-14A WST COMMUNICATIONS REQUIREMENT

1. Ownship Data - to central node

   Ownship location

   Position Rates

   Ownship Attitude

   Attitude Rates

   Aero Configurations: Stores, Wheels, Flaps-Slats

2. Situational Data - from central node

   Targets Positions & Rates

   Targets Attitudes & Rates

   Targets Types

   Threats and EW Signatures

   Other Environmental Data

3. Controls Data - bi-directional

   Simulator Run Control

   Exercise Initialization

   Performance Monitoring

4. Voice - bi-directional

   Radio Communication

   Instructor Role-Play Message

3.1.3 The F/A-18 Trainer [Ref. 5]: The F/A-18 Operational Flight Trainer, Device 2F132, consists of a single position cockpit, a visual display system, an instructor station, and their related equipment activated by a digital computer complex.

3.1.3.1 The Intended Use: The F/A-18 OFT provides training in the development of pilot skills and techniques to efficiently fly the F/A-18 aircraft. The OFT supports training for operations under both normal and emergency conditions. The training provides for proficiency in the operation of controls, interpretation of instruments and displays, operation of navigation and communications systems. For its current configuration, the F/A-18 OFT provides weapons management and air to ground delivery. In a networking environment, the scope of training can be extended to include formation flights and air-to-air operations.

3.1.3.2 Data Communications Requirements: The data communications requirement is similar to that for the F-14A WST.

3.2 PROPOSED NETWORK SOLUTION

The proposed network is synthesized to satisfy the simulator network requirements while coping with the constraints of the available techniques and technologies.

The discussion of the network solutions here starts with the key design considerations which led to the choice of the proposed system configuration and the system operating scheme. The proposed network is then presented. The implementation requirements for the proposed network are treated in the following section.

3.2.1 Design Considerations: The study of the simulator network requirements points to the following key design considerations that have to be addressed by the proposed network solution.

(1) The network instructor operator station (NIOS) functions

(2) The data transfer medium throughput constraints

(3) The synchronous data transfer requirements

(4) Computer Architecture

3.2.1.1 The NIOS Functions: The networking of simulators implies a training scenario where a tactical environment is enacted and interacted by a group of trainees under the direction and control of the instructional staff. The design implications are two-fold. One is that the NIOS functions require extensive computational resources for carrying out the training exercise. The other is the need for data communications with the individual simulators, and to serve as the clearing house for data transfer among the simulators. The above two considerations naturally identify the network instructor functions as the focal points of the network system. As such, a set of dedicated

computer resources is proposed as the means for achieving the performance of the NIOS as well as for supporting the data exchanges among the simulators within the network.

3.2.1.2 The Data Transfer Medium: In networking existing simulators located at sites in different parts of the country (such as the E-2C and F-14 simulators), long distance communications media must be used to transmit and receive data in real-time. Such long distance data transmission media represents the bottleneck for data flow. Thus for networks requiring long distance communications, the availability and affordability of the communication medium defines the limit on networking performance in terms of dynamic response and the number of simulators in the the network. In order to fully utilize the limited resources, various means of trading computational resources for fuller and more efficient use of the communication medium were devised. For example, rather than sending full position vectors of 32 bits per component each frame, a delta vector of 20 bits per component could be used by the receiving computer to compute the new position. The significant design choice here is the use of dedicated communications processors at both ends of the communication medium. The communication processors allow full time use of the communication line for transmission, while at the same time serving as the interface with the individual simulator computers and the NIOS computer. In the proposed design, the communications processors take the form of single board computers (SBC's) that might be commercially available. For a given network, the same type of single board computer should be used as communications processors at all nodes. A practical choice would be a board hosted in a popular backplane such as VME, for which commercial interfaces to several different minicomputer busses are available. If the same family of computers is used at all the nodes, it may be possible to host the SBC's and phone line interfaces in the native I/O bus. For the case of the F-14 and E-2C trainers, SEL computers are used for both and the MP bus could be considered for this purpose.

3.2.1.3 Synchronous Data Transfers: Unlike the situation within a training system where the synchronization of software module execution to a framing structure is fundamental to the accuracy of the solutions of the equations, there is no mathematical need to synchronize the frame structures of all the simulators participating in an integrated exercise. The major consideration for realism is the effect of transport delays and network delays. It is, of course, necessary to preserve the framing of the data which is exchanged. This can be accomplished by moving all the data from the sender's shared memory into the communications processor buffer at the end of each frame. Similarly, the receiver communications processor transfers the last packet received to shared memory at the end of the local frame for use by the simulation computer in its next frame. Data is sent across the 56K duplex line whenever the communications processor has assembled a packet, the data content of which is a frame of data. If the trnsfers can all be accommodated after all modules have executed and before the start of the next frame, then no discrete frame delays are incurred. If the transfers, because of bandwidth considerations, need to be spread over an entire frame, then a penalty of 1 frame time is incurred. This, in fact, is the case for the network proposed.

3.2.1.4 Computer Architecture: The advantages of a distributed computer architecture are many fold. But the availability of low cost single board processors makes it practical as a design choice. This is an enabling factor for both the NIOS implementation and for the communications processors.

The physical realization of the computer complex follows that of any commercially available distributed processor system. The distribution of computational loads to the processors follows the partitioning of the networking functions which include the various NIOS functions, and the communications support functions among the many sources and destinations.

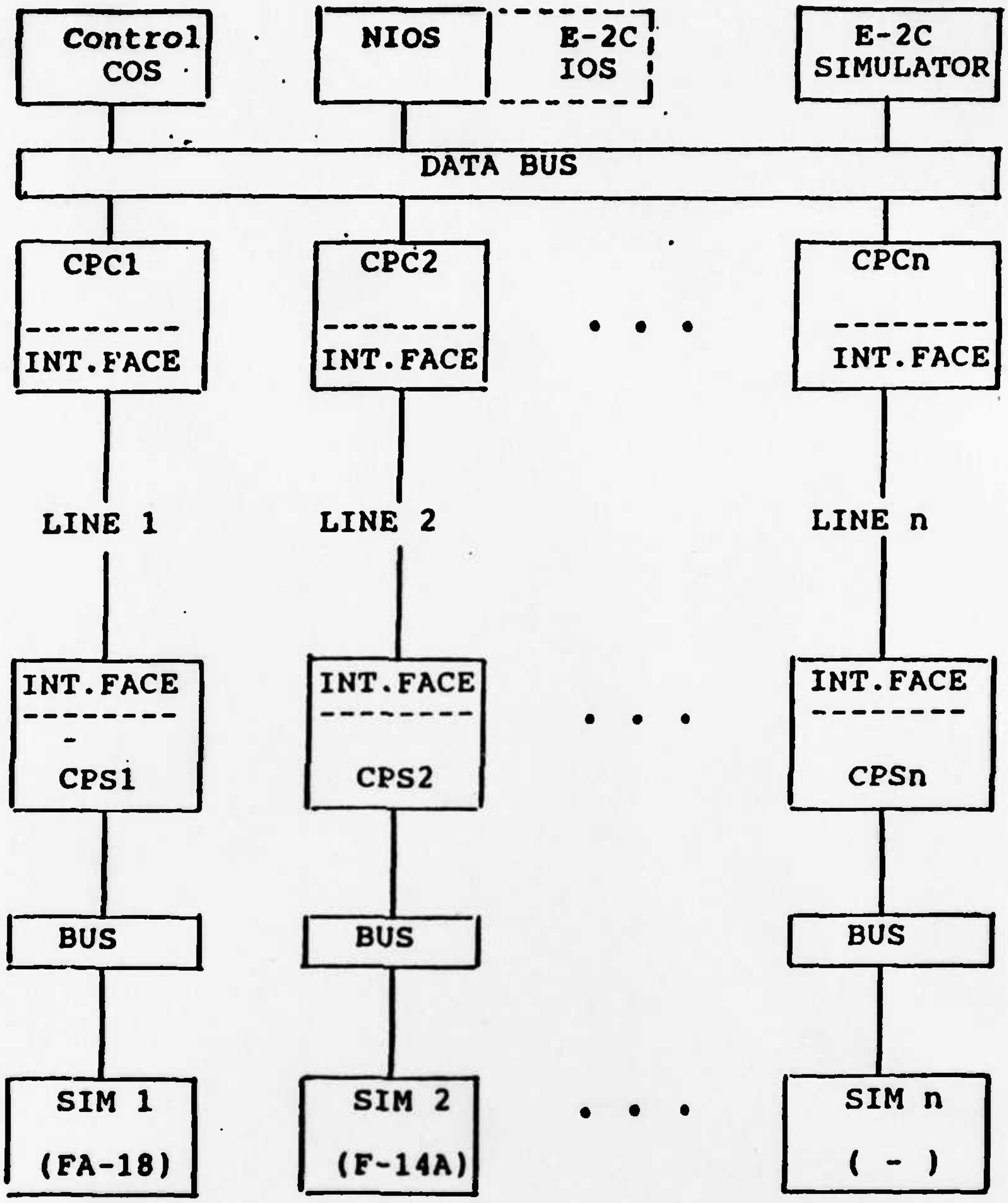
3.2.2 Network Configuration: The proposed configuration for the simulator network is shown as Figure 5. In the network, a dominant node will control and coordinate the high speed data transfers on the central site computer bus. The communications processor pairs (CPC1, CPS1) (CPC2, CPS2)...(CPCN, CPSN) serve the function of performing rapid (5% of frame time) data exchange between the host computer and the concentrator's buffer to allow 95% utilization of the serial data links. The proposed network configuration is specifically chosen for networks involving simulators at separate and distant locations, which is the case of networking E-2C and F-14 trainers. The two fundamental characteristics are that:

(1) The Network Instructor Operator Station (NIOS) processor is used to initialize and control the network.

(2) The communications processors at the central site communicate with the (NIOS) through a high speed parallel bus, while the long distance data communications channels are handled through serial I/O ports and 56K phone lines in a star network configuration. At the outlying simulator ends, the remote communications processors communicate with the simulator computers through the host computer parallel buses or possibly through VME or the like. The network, as configured, provides for the following three salient features:

(a) Data Channel Utilization: The communications processors support almost 100% utilization of the data channel capacity. The expense of the long distance communications channels makes this characteristic a key technical requirement in achieving the feasibility for long haul networking of simulators.

(b) Network Size: The use of local communications processors and the corresponding parallel bus data transfer rates make it possible to include a large number of simulators in the network. The number is limited essentially by the amount of time each frame that the communications processors can gain access to system memory and the bandwidth of this channel. If, for example, 50 communications processors each required dedicated access to system memory for 1% of the frame time, only 50% of the frame time would be available for system memory accesses. If the parallel bus at the central node supports multicast operations, common data could be sent to all communications processors simultaneously, and the bus loading could be substantially reduced, allowing more simulator nodes to be added to the network.



CPC1: Communications Processor at Central Site
CPS1: Communications Processor at Simulator Site 1
SIM1: Simulator No. 1

FIGURE 5. PROPOSED NETWORK CONFIGURATION

(c) Simulator Impact: The impact on the simulators themselves of adding the proposed network would be due primarily to the loading placed on the internal computer system busses by the communications processors data transfer functions. In the case where the simulator-to-communications processor transfers are accomplished after all modules have executed, there is virtually no impact. Where these transfers occur throughout the frame, the impact is a direct function of the number of parameters involved. In the case of the E-2C/F-14 network, it should not be substantial. The incorporation of bus traffic minimization algorithms should impose only negligible computational requirements on the simulator computers.

3.2.3 Implementation Requirements: The networking solution previously proposed is examined here in terms of the various factors pertaining to the physical realization of the proposed solution. The factors are presented under the following two categories of implementation requirements: (1) Network Dynamics and (2) Network and Training Exercise Control. These categories follow directly from the networking requirements delineated previously in Section 2. The feasibility of networking simulators for integrated training exercises depends on the ease and the extent to which the implementation requirements can be satisfied.

3.2.3.1 Network Dynamics: A first order and intuitive concern in networking simulators is the data transfer delays caused by the data exchanges between the simulator computers and the communications processors and also by the data transmission process itself. Furthermore, it is true that such delays are unavoidable. It is therefore necessary to treat the data transfer delay issue by understanding (1) the causes and source of delays, and (2) the effects of delays as well as the limits of tolerance on delays. In other words, we seek to understand the cause and effect of data transfer delays such that adequate dynamics can be achieved for the integrated network without the use of excessive communications resources. The delays are mainly due to the transmission medium and to the computational frame structure.

3.2.3.1.1 The Transmission Medium: The physical transmission of data involves the use of processors and a transmission medium such as a phone line or some form of data bus, each with a concomitant component of overall transport delay. For networking tasks within the geographic confines of a local area network, the feasibility of networking simulators can be readily achieved. The data throughput of local area networks limits the time impact on simulator processors to less than 1% of the simulator frame time. In cases where long haul data transmission distances are involved, the data transmission medium becomes a prime contributor to transport delay. A frequently used figure for commercial satellite up-down time is 1 second which is probably an intolerable figure for networked flight simulators (see Sec. 3.2.3.1.3). If a satellite could be found which would introduce delays no longer than 250 milliseconds, it would be a viable option. If not, land lines would have to be employed.

3.2.3.1.2 Computational Frame Delays: For the network proposed, data concentration and inter-node transfers could be distributed over most of the frame, in which case a 1-frame delay would be introduced with the F-14, for example, operating in frame n on the E-2C's data from frame n-2. If the data

concentration and exchange functions were compressed into the last part of each frame, this delay would be removed. The latter case would only be possible if the data transfer requirements were minimal or if the bandwidth of the transmission medium were expanded. In either case, the central node must ensure that data transfers between outlying sites in the star network, be adjusted, if necessary, to maintain proper framing.

3.2.3.1.3 The Dynamic Response: The dynamic response of training devices has been a subject of extensive studies and experimentation through the years. The wealth of information on simulator dynamics points to time lag and/or transport delay as major causes of unsatisfactory simulator performance, including simulator sickness. However, the formulation of systems dynamic requirements must differentiate between the man-in-the-loop case and cases where the same time delays cause time skew in the training scenario. In the man-in-the-loop case, the causal relationship is very closely coupled. This is due to the fact that typically an operator who closes the cause/effect loop is aware of the interaction onset and is capable of resolving or perceiving very small time lags or delays. This is especially acute whenever visual cues are part of the interactive activities; such as in the case of flight operations. In such closed-loop applications a delay in excess of 100 msec. is unacceptable.

Fortunately, the delays introduced by the process of networking do not enter into the above-mentioned closed loop cases. An event caused by one operator (e.g., aviator A) can be observed or acknowledged by another operator (e.g., Aviator B in a separate aircraft) after a finite time delay without noticeable effects. This time delay can be as much as a quarter of a second, and in a tactical environment such magnitude of time skew in the exact instant of action onset is considered to be tolerable. In order to assess trainee operators' performance, a self consistent set of parameters must be used by the local IOS. Within the confine of the local IOS, the trainee will be evaluated under a localized set of metrics. In other words, the IOS, evaluates the trainee performance using a set of spacial and temporal measures as "perceived" by the IOS, together with the time increment resolution inherent in the individual simulator design (unaffected by networking).

A recent study [Ref. 6] on impact of network delay on air-to-air simulation at Air Force HRL provides data supporting the notion that networking delays pose little, if any, degradation of training fidelity. The results of this study show that at least for the maneuvers tested, a delay of 250 msec. can be accepted with only a slight degradation. The use of a predictive filter could possibly extend this delay tolerance.

3.2.3.1.4 Network Data Loading Analysis: The estimated data communications volume for the E-2C/F-14 network is shown in Table 2. This loading analysis was made for the purpose of addressing the feasibility issue. As such, the estimates can be viewed as the outcome of a budgeting process which allocates the network resources among the various simulator functions and their corresponding communications needs.

There were various design assumptions such as the representation of position by means of a base plus increments; with only the position increments (Ownship location at 20 bit word length for increments and 32 bit word length for total location representation) being transmitted on the network for every simulator time frame.

TABLE 2. DATA COMMUNICATIONS THROUGHPUT REQUIREMENTS

Function	# bits/info	Update Rates	# bits/sec
Ownship Loc.	3x20 = 60	30/sec	1,800
Loc. Rate	3x 8 = 24	30	720
Ownship Attitude	3x12 = 36	30	1,080
Attitude Rate	3x 8 = 24	30	720
Weapon's Effects	1x60 = 60	30	1,800
Other Data Communication such as systems status monitoring, instructional data & control, etc., plus overhead due to encryption and network protocol			20,000
	Total Data Rate	(Bits/Sec)	26,120
	Assuming 95% channel use/frame	(Bits/Sec)	27,495

Alternatively, a design choice can be made to use a 20 bit word length as the total location representation if a smaller gaming area is used in any given implementation case.

This same budgeting approach is applied to other parameters, such that together with simulator iteration rates, a tentative fit between data transfer requirements and the network resources can be established for feasibility judgment.

If the data update rate is set at 30 Hz, the communication channel must have a capacity of approximately 27,500 bits/sec. This channel requirement suggests the choice of a 56K line since a 19.2K line would not be adequate. If a T1 line is already in use between the two sites of interest, the simulator networking application could make use of a subchannel of this line. The Defense Commercial Telecommunications Network, if available, could also be used for this purpose.

Given that data update rates much less than 30 Hz could be adequate for stationary threats and for weapons effects, there exists a considerable range of choice for an affordable and reliable communications medium.

3.2.3.2 Network and Training Exercise Control: The many aspects of implementing the NIOS (Network Instructor Operator Station) are discussed in the subsequent paragraphs to assure feasibility of meeting the network and training exercise control requirements as stated previously in Section 2.2.2.

3.2.3.2.1 Physical Characteristics: The NIOS implementation is supported by a dedicated processor identical to those serving as the communications processors. Due to the specific tactical training environment, the E-2C simulator functions provide for a natural focus for the training missions. Thus the NIOS should be collocated with the E-2C IOS such that the instructional staff are provided with ready access to all the E-2C instructional displays and control functions without duplicating the E-2C instructional staff. The NIOS equipment and the communication processors are modest in physical size, power consumption, and heat loads. A first order approximation of the facility requirements is that akin to the requirements for a personal computer installation. Without the benefit of actual facility surveys, it is still reasonable to assume that the additional equipment can be accommodated within the existing facilities.

3.2.3.2.2 Runtime Control: The NIOS computer receives instructor inputs and in turn generates the appropriate control signals in the form of commands and processor interrupts. Through the previously mentioned signal path, the NIOS coordinates and controls the initialization process.

Another major function of the NIOS processor is that of serving as the data exchange clearing house. The NIOS receives all data transmitted from the individual simulators through the communication processors. In return, the NIOS processor sorts the data and, if required, distributes them to the proper simulator destinations via the communication processors. The advantage of such a data transfer scheme is that it is conceptually straightforward and the software implementation is uniform and therefore easily reusable.

3.2.3.2.3 Data Link Simulation: The data link operation is an important element in the tactical environment. Obviously, however, the transmission of such data over the simulator network requires appropriate safeguarding measures. In cases where the security cannot be guaranteed, alternative simulation techniques should be explored. One alternative approach for providing the data link function is to parameterize the data link operation. By transmitting a set of parameters describing the expected data link operations, the individual simulators will use such parameters to generate the proper data link manifestation to the trainees. Therefore, a mathematical model for data links has to be added to the individual simulators. Generally speaking, this approach represents a means of trading between the use of communications resources and computational resources.

3.2.3.2.4 Training Exercise Planning: The requirements for network training exercise planning and exercise generation are unique to the network

environment. As stated in section 2.2.4, the software development for such functions will require substantial resources. Furthermore, the intrinsic complexity of the software tasks plus the many parties involved (different sites, trainee organizations, etc.), point to added development risks. Thus, the implementation of the exercise planning and exercise generation capability is identified as the highest risk; and potentially the single highest development cost item.

However, the challenges in satisfying the exercise planning will bring about improvements in training effectiveness of the simulator network. The exercise planning area also represents a suitable application for expert systems and other computer based training techniques.

The NIOS processor also supports the network operations scheduling function. The schedule is to be generated by the exercise planning activities. The run control function selects and activates the appropriate operating schedule according to instructors' input choices at the NIOS console. The NIOS is also responsible for data logging and for issuing exercise control commands such as run and freeze.

SECTION IV

INDUSTRY VIEWS

Various manufacturers and research establishments have been contacted for their views on simulator networking. The composite inputs from the parties contacted are summarized as follows:

4.1 The Training Needs and Objectives: The need for interactive training environments for large numbers of trainees was well recognized. The most focused view on the training needs and training objectives for simulator networks was provided by the AF study efforts on multi-aircraft battle simulators [Ref. 7]. The industry members' views tend to assume that the training needs and objectives were to be established by front end studies; upstream of their usual work scope. In addition to eager expectations of what the "spec" will carry, a lot of brain storming and discussion on simulator network applications took place in terms of device capabilities. The overall observation here is twofold. (1) There is a very high level of interest among the industry members. Although the training needs and objectives were not clearly envisioned, they were excited by the business potential of the simulator networks. (2) The need for research and development in the instructional capabilities area was identified as the major challenge in implementing a network solution.

4.2 The Technology: The survey presented no significant lack in the technologies in the component simulators that individual manufacturers currently produce. These include armor trainers (SIMNET) [Ref. 8], flight and Naval tactics (including action and speed trainers).

The technology barriers exist in the use of longhaul communications media in terms of the effects of transport delays. The long transport delays due to the use of communication satellites are not acceptable for air to air combat training. However in training applications with low velocity vehicles or in applications where vehicle dynamics are not explicitly simulated (such as in the case of naval tactics simulator), transport delays can be tolerated readily.

4.3 Costs and Resources: In order to achieve affordability, significant cost reduction in trainee stations must be achieved. The other perceived requirement for simulator networks is that the component simulators must also achieve a significant improvement in reliability/availability.

In the area of OFT's, the above cost and reliability requirements point to simulators with reduced simulation scope. As such, cost reduction is achievable given the larger production lot size. In a broad sense, SIMNET serves as a good example towards that direction.

A more difficult challenge is in the area of sensors simulation, especially that requiring visual simulation. The current cost and complexity levels of both the visual image generators and the display subsystems are very high for devices suitable for air combat simulator applications.

Substantial cost reductions are attainable, but would require substantial investments in research and development efforts aimed at large production lots.

SECTION V

CONCLUSIONS

The main conclusion of this study is that networking of complex simulators is feasible. A simulator network can be specified and physically realized by means of available techniques and technologies. In order to place the above conclusion in perspective, the following three considerations are provided as a frame of reference:

5.1 The Need for Simulator Network: The single most compelling motivation for networking simulators/trainers is the need for a means to provide "situational awareness" training. It is widely perceived that mission survival rates improve dramatically after aircrews successfully complete the first few missions. The high incident rate during the initial operating periods is considered to be attributable to the lack of combat experience in correctly and completely assessing the battle situations. Situational awareness becomes progressively burdensome as the pilot has to cope with the following factors which tend to increase the information load:

(a) Weapon system complexity: This tends to increase the task complexity for the pilot.

(b) Weapon system performance: Higher performance causes events to occur within shorter time span thus allowing less awareness and reaction time.

(c) Threat environment: Increases in sophistication, numbers, types, and performance of threats contribute directly and substantially to pilot task loading.

If the use of networked simulators can provide the experience equivalent of the first missions, the feasibility of such networks points to a direction for achieving significant improvements in mission survival rates.

5.2 Operations: A secondary but important motivation for a networked simulator is the possibility of distributing training capabilities to operational sites. The availability of simulator networks opens up a means of information exchange and skills interaction among users. The simulator networks also serve to provide the "context" upon which tactical ideas/strategy and experimentation can be carried out through interactive enactment. Simulator networks can also reduce the time and expenses associated with trainees traveling to the site of the simulator. However, the approach of distributing simulator training to operational sites implies that large numbers of simulators are required to support the training needs. The use of complex simulators within a network context is technically feasible, but not affordable. That is, in order to successfully exploit the advantages of simulator networks, the availability of very low cost individual simulator is a prerequisite.

5.3 Implementation: Among the various aspects of simulator network implementation investigated during the course of this study, the item which requires most developmental efforts is the implementation of the network

instructor operator station (NIOS) function. Unlike other areas, including computer networking techniques, the NIOS requires totally new design efforts in terms of instructional system development, network control, and operational support/coordination. This implies that a substantial investment is required to develop the NIOS software. However, the recurring costs of the NIOS could be modest if software reusability were achieved as a design goal. This architectural aspect, together with the choices of communications media are discussed below.

5.3.1 Architecture: The recommended architecture for networking training systems at different sites is shown in Figure 5. The key feature is the use of dedicated, common communications processors at each node to serve as interfaces between the simulator host computers and the serial transmission medium. This concept is equally applicable to the situation in which simulators are connected via a Local Area Network. In the case of dissimilar simulator host computers, an open-architecture, well-supported bus such as VME could be used to host these processors. Where the simulator computers have a common I/O bus, the communications processors could be designed for it. For the particular case of the E-2C and F-14, the SEL MP bus could be used for this purpose. Voice transmissions would have to be made over separate telephone lines or, if use were made of the Defense Commercial Telecommunications Network, the same lines could be used for voice and data. The added costs of the communications processors represent modest investments which enable the use and reuse of a common set of communications and controls software. The savings in software development, update and maintenance could be substantial. The software reusability aspects and the hardware commonality are especially significant in view of the following considerations.

(1) The Network IOS interface with the communication processors can remain unchanged through varied applications. This avoids the redesign of exercise compilation (or authoring) software.

(2) The interfaces between the individual simulators and their dedicated communications processors can be implemented under flexible time schedule and computing resources allocations. In other words, the implementation of the interface between any one individual simulator and its communication processors can be carried out as an isolated task with reduced complexity and constraints. This makes the simulator networks logically more understandable.

(3) The reuse of the NIOS package and parallel implementation of simulator interfaces can substantially reduce leadtime in addition to cost savings.

5.3.2 Transmission medium: The choice of transmission medium is based upon bandwidth requirements, physical distance between the simulators, and availability. The bandwidth requirement for linking E-2C and F-14 Weapons Systems Trainers is estimated to be 27,500 bits per second. For cases in which the simulators are in close proximity, a Local Area Network such as the 10 megabit per second Ethernet would be a viable choice. Where long-haul communications are required, choices include AT&T's Dataphone Digital Service 56K line, a subchannel of a T1 line if available, and an additional service on the Defense Commercial Telecommunications Network if it is available. Unacceptable delays introduced by commercial satellites probably dictate the use of land lines.

SECTION VI

RECOMMENDATIONS

6.1 Feasibility: Networking of existing training systems such as the E-2C and F-14 Weapons Systems Trainers is technologically feasible. Before attempting the actual implementation, however, a cost/benefits analysis should be performed and an assessment should be made of the ability to coordinate the different fleet organizations which would be involved in integrated training exercises.

6.2 Large Simulator Networks: In order to make affordable simulator networks with large numbers of nodes, a significant reduction in individual simulator cost must be achieved. Such cost targets can only be achieved through redefining simulator requirements to include only the capabilities to support the main objective of the integrated training such as "situational awareness". Technological innovations in visual scene generation and OFT implementations in large production lot sizes will also contribute to cost reduction. The candidate list for OFT complexity reduction could include the deletion of simulation requirements for landing gear, ground effects and other aero simulation, fire alarm, fuel system, selected navigation systems, environmental control system, landing lights, cable hooks, etc. In other words, the simulator network could be comprised of special purpose (and low cost) OFT"S and/or WST's. The traditional role of the simulator/trainers will continue to be served by the existing simulator types. Proposed here is a concurrent effort within the simulator network testbed project to develop special purpose, low cost simulators for network applications.

6.3 Standardization: For networks of large numbers of simulators, the identification of selected simulator modules for implementation as standard items may lead to both substantial cost and lead time reductions. This is especially significant in terms of software reusability. The standardization effort may start with a dissection of simulator subsystem functions to identify and define candidate modules [Ref. 9] for standardization, and selected modules could be defined and implemented as standard items. For example, within the context of simulators for network applications, visual scene generators would represent a hardware intensive module for standardization. Meanwhile, the NIOS represents a prime candidate for Ada based reusable software. Thus the NIOS is a key simulator network testbed development item which may also be used for demonstrating standardization.

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